IEICE Electronics Express, Vol.8, No.7, 484–490

# Design of concentric ring antenna arrays for isoflux radiation in GEO satellites

**Alberto Reyna**[1], **Marco A. Panduro**[2a)], **and Carlos del Rio**[1]
[1] *Universidad Pública de Navarra*
*Campus Arrosadia, 31006, Pamplona, España*
[2] *Universidad Autónoma de Tamaulipas, UAMR-R*
*Carretera Reynosa-San Fernando, Reynosa Tamaulipas, 88779, México*
a) *mamendoza@uat.edu.mx*

**Abstract:** The design of concentric ring arrays for isoflux radiation is reported in this paper. This design considers the reduction of the side lobe level and the isoflux radiation requirements for Geostationary Earth Orbit (GEO) satellites. The optimization problem considers the spacing between rings and the levels of amplitude excitations. The well-known method of Particle Swarm Optimization (PSO) is utilized for the optimization. The obtained results could lead the satellite hardware to be reduced significantly even more that results presented previously in the literature.

**Keywords:** concentric ring array, isoflux radiation, GEO satellites, particle swarm optimization
**Classification:** Microwave and millimeter wave devices, circuits, and systems

## References

[1] S. G. Hay, D. G. Bateman, T. S. Bird, and F. R. Cooray, "Simple Ka band Earth coverage antennas for LEO satellites," *IEEE Antennas Propag. Symp.*, vol. 1, pp. 708–711, July 1999.
[2] W. Aerts and G. A. E. Vandenbosch, "Optimal inter-element spacing in linear array antennas and its application in satellite communications," *34th European microwave conference*, 2004.
[3] T. Koleck, "Active antenna coverage synthesis for GEO satellite using genetic algorithm," *Antennas Propag. Society Int. Symp.*, vol. 1, pp. 142–144, 2003.
[4] J. Jin, H. L. Wang, W. M. Zhu, and Y. Z. Liu, "Array patterns synthesizing using genetic algorithm," *Progress In Electromagnetics Research Symposium*, March 2006.
[5] A. F. Morabito, A. R. Lagana, and T. Isernia, "On the optimal synthesis of ring symmetric shaped patterns by means of uniformly spaced planar arrays," *Progress In Electromagnetics Research B*, vol. 20, pp. 33–48, 2010.
[6] M. C. Vigano, G. Toso, P. Angeletti, I. E. Lager, A. Yarovoy, and D. Caratelli, "Sparse antenna array for earth coverage satellite applications," *Proc. Fourth European Conference on Antennas and Propagation (EuCAP)*, April 2010.


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011

IEICE Electronics Express, Vol.8, No.7, 484–490

[7] R. L. Haupt, "Optimized element spacing for low sidelobe concentric ring arrays," *IEEE Trans. Antenna Propag.*, vol. 56, no. 1, pp. 266–268, 2008.
[8] L. Biller and G. Friedman, "Optimization of radiation patterns for an array of concentric ring sources," *IEEE Trans. Audio Electroacoust.*, vol. 21, no. 1, pp. 57–61, 1973.
[9] J. Robinson and Y. Rahmat-Samii, "Particle swarm optimization in electromagnetics," *IEEE Trans. Antennas Propag.*, vol. 52, pp. 397–407, 2004.
[10] R. C. Eberhart and Y. Shi, "Particle swarm optimization: Developments, applications and resources," *Proc. Congress Evolutionary Computation*, pp. 81–86, 2001.
[11] A. Reyna and M. A. Panduro, "Design of steerable concentric rings array using rotation properties and evolutionary optimization," *Proc. Fourth European Conference on Antennas and Propagation (EuCAP)*, April 2010.
[12] M. A. Panduro, C. A. Brizuela, L. I. Balderas, and D. Acosta, "A comparison of genetic algorithms, particle swarm optimization and the differential evolution method for the design of scannable circular antenna arrays," *Progress in electromagnetic research B*, vol. 13, pp. 171–186, 2009.

## 1 Introduction

The recent demand for GEO satellite applications includes two important factors: the reduction of the antenna hardware such as physical dimensions and the excitation devices, and secondly, an isoflux radiation, i.e., a uniform and ring-symmetric shaped pattern to illuminate the earth surface [1]. In [2, 3, 4], it has been considered uniform linear and planar arrays for satellite applications by using excitations which implies higher complexity of hardware. Recently, relevant contributions have been proposed in the literature using some deterministic approaches for synthesizing uniform and sparse planar arrays to obtain a desirable isoflux radiation pattern [5, 6]. However, these contributions still consider many excitation devices (amplitudes and phases) in a rectangular planar array. In fact, a significant deviation to achieve a radiation mask in some angular range is observed out of the field of view in [6].

In this work, it is reported the study of a radial geometry for an array, i.e., the design of a concentric ring array for reducing the hardware of the antenna system; in [7, 8], it has been presented the properties of concentric ring arrays such as symmetric pattern in both azimuth and elevation planes. Specially, in this paper, it is investigated the behavior of the radiation pattern optimizing the spacing between rings in the array and the levels of amplitude excitations. It is selected the spacing between rings as an optimization variable to obtain a unequally distribution of the radius of the rings. Therefore, the main contribution of this research is the synthesis of a concentric ring array for GEO satellite applications involving less excitations devices to accomplish the desirable shape pattern with side lobe level reduction. This synthesis is


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011

IEICE Electronics Express, Vol.8, No.7, 484–490

performed by using the particle swarm optimization (PSO) [9]. Until now, to the best knowledge of the authors, an evolutionary algorithm for global optimization in concentric ring array for desirable isoflux radiation in GEO satellites has not been considered yet.

## 2 Concentric ring array model and problem statement

Let us consider a concentric ring array of $N_T = 1 + (N_n N_r)$ elements spaced on the plane X-Y. The array factor for this concentric ring array is given by [7]

$$AF(\theta, \varphi, S, W) = 1 + \sum_{n=1}^{N_r} \sum_{m=1}^{N_n} w_{nm} \exp\{jkr_n[u \cos\varphi_m + v \sin\varphi_m]\} \tag{1}$$

where $u = \sin\theta \cos\varphi$, $v = \sin\theta \sin\varphi$, $N_r$ represents the number of rings, $N_n$ represents the number of elements on the ring $n$, $\lambda$ is the signal wavelength, $k = 2\pi/\lambda$ is the phase constant, $\varphi_m = 2\pi(m-1)/N_n$ represents the angular position of the element $m$ on the ring $n$, $\theta$ is the angle of a plane wave in the elevation plane, $\varphi$ is the angle of a plane wave in azimuth plane, $r_n$ is the radius of ring $n$. The radius of each ring defines the spacing between rings in the next way $s_1 = r_1$, $s_2 = (r_2 - r_1)$, $s_3 = (r_3 - r_2), \ldots, s_n = (r_n - r_{n-1})$ which are arranged in the set of real numbers $S = \{s_1, s_2, \ldots, s_N\}$. In addition to, $w_{nm}$ represents the amplitude excitation of the element $m$ of the ring $n$ defined in the set of real numbers $W = \{w_{11}, w_{12}, \ldots, w_{1m}, \ldots, w_{21}, w_{22}, \ldots, w_{2m}, \ldots, w_{NT}\}$. This model considers the center of each ring as the phase reference in the array factor.

GEO satellite antenna systems provide an isoflux radiation with no variation in the strength power density to any point of the illuminated earth surface as long as the satellites are spinning around the earth. Since this framework, we propose an accurate prescribed pattern that can be calculated as a function of $R_s(\theta)$ in the coverage area as follows:

$$R_s^2(\theta)\left(\frac{\sin^2\theta}{b^2} + \frac{\cos^2\theta}{a^2}\right) + R_s(\theta)\left(\frac{-2(h+a)\cos\theta}{a^2}\right) + \left(\frac{(h+a)^2}{a^2} - 1\right) = 0 \tag{2}$$

The function $R_s(\theta)$ is the prescribed pattern that indicates the relative distance of the satellite to any point of the illuminated earth surface; $h$ represents the height of the satellite; $a$ is the equatorial radius of the earth; $b$ is the polar radius of the earth. In this case, the design problem of this study is to optimize the spacing between the rings and the semi-uniform excitations for a concentric ring array considering the zone of coverage involving the conditions of the prescribed pattern $R_s(\theta)$ and the reduction of the side lobe level. The optimization is constrained by the minimum spacing between the rings of $s_{min} \geq 0.5\lambda$ and the spacing between the antenna elements in the ring $n$ as $q_n = 2\pi r_n/N_n$. For this optimization process, the maximum aperture might be $A_{max} = N_r s_{max}$ in both axis. In this case $s_{max}$ is the boundary in the search space of $S$. The spacing between rings is established to be in the range of $0.5\lambda \leq s_n \leq 1\lambda$. The levels of amplitude excitations are arranged


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011

in a vector of real numbers $L = \{l_1, l_2, \ldots, l_g\}$ where $l_g$ is the excitation value feeding a group of rings of the array, i.e, an excitation value feeding a sub-array.

In this work, the PSO is utilized to synthesize the concentric ring array to achieve the desirable isoflux shape pattern. In this case, each particle is represented by the spacing between the rings $S$ and the levels of amplitude excitations $L$. Then, the particles within the swarm move influenced by its current position, its memory and by the cooperation or social knowledge of the swarm [9], using only one operator, the socalled velocity operator. Let us suppose a swarm of $K$ particles, in which each particle $X_K = (x_{k1}, \ldots, x_{kD})$ representing a potential solution ($S$ and $L$) is defined as a point in a $D$-dimensional space. The limits of the parameters $x_{kd}$ to be optimized define the search space in $D$-dimensions. Iteratively, each particle $k$ within the swarm flies over the solution space to a new position $X_K$ with a velocity $V_K = (v_{k1}, \ldots, v_{kD})$, both updated along each dimension $d$, by the following:

$$v_{kd} = wv_{kd} + c_1 r_1 (pbest_{k,d} - x_{kd}) + c_2 r_2 (gbest_d - x_{kd}), \quad v_k \leq v_{d,\max} \forall d \quad (3)$$

$$x_{kd} = x_{kd} + v_{kd}\Delta t \quad (4)$$

where $w$ is known as the inertial weight, $c_1$ and $c_2$ are the acceleration constants and determine how much the particle is influenced by its best location (usually referred as memory, nostalgia or self-knowledge) and by the best position ever found by the swarm (often called shared information, cooperation or social knowledge), respectively. Moreover, $r_1$ and $r_2$ represent two separate calls to a random number function U[0, 1], $v_{dmax}$ is the maximum allowed velocity for each particle used as a constraint to control the exploration ability of the swarm and usually set to the dynamic range of each dimension [10], and $\Delta t$ is a time-step usually chosen to be one. In PSO, the population size, the inertial weight and the acceleration constants summarize the parameters to be selected and tuned. For the optimization in this research, the fitness function of the design problem is formulated as follows:

$$\begin{aligned} of = {} & |AF(\theta_r, \varphi, W, S) - R_s(\theta_r)|^2 \\ & + |AF(\theta_{SLL}, \varphi_{SLL}, W, S)/\max(AF(\theta, \varphi, W, S))| \end{aligned} \quad (5)$$

where $\theta_r$ is the range of the elevation plane for the coverage area above the earth, and $(\theta_{SLL}, \varphi_{SLL})$ is the angle where the maximum side lobe level is attained.

## 3 Simulation results

The synthesis of an isoflux radiation for a concentric ring array was implemented by the method of PSO. Pursuant to the $WGS84$ (World Geodetic System 84) coordinate system, the dimensions of the earth are: the equatorial pole $b = 6356752.314$ meters and the polar pole $a = 6378137$ meters. In the prescribed pattern for GEO satellites with an altitude of 36000 km, an angle of elevation of $\theta_0 \approx 9°$ is enough to illuminate the earth with an


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011

attenuation of $-1.3\,\mathrm{dB}$ in the nadir direction $\theta = 0°$. In order to make a fair comparison in terms of number of elements $N_T$ and maximum aperture $A_{max}$ with respect to a uniform and sparse planar array designs presented previously in the literature, we choose the specifications of the design presented previously in [5]. In this case, the design presented in [5] considers less antenna elements and less excitations with respect to the case presented in [6] Then, it is proposed $N_T = 61$ elements as in [5], but in this case distributed in $N_r = 4$ rings. Thus, the number of elements for each ring is $N_1 = 6$, $N_2 = 12$, $N_3 = 18$ and $N_4 = 24$. This distribution also considers a central element placed on the origin. In order to decrease as the best as possible the number of antenna excitations, it is proposed two antenna designs: the first design is fixed for 3 levels of amplitude excitations where the level $l_1$ is for the central element and the rings $n = 1, 2$; $l_2$ is for the rings $n = 3$ and $l_3$ is for the ring $n = 4$. The second design is fixed for 2 levels of amplitude excitations where $l_1$ is for the central element, and the rings $n = 1, 2$; $l_2$ is for the rings $n = 3, 4$. The parameters of the PSO are set as follows: maximum number of iterations $i_{max} = 1500$, number of particles $p_{size} = 200$, inertial weight $w$ varies downwardly in the range of [0.95-0.4] through the optimization process and the acceleration constants are $c_1 = c_2 = 2$. We select these parameters for their proper performance that has been studied in previous works [11, 12].

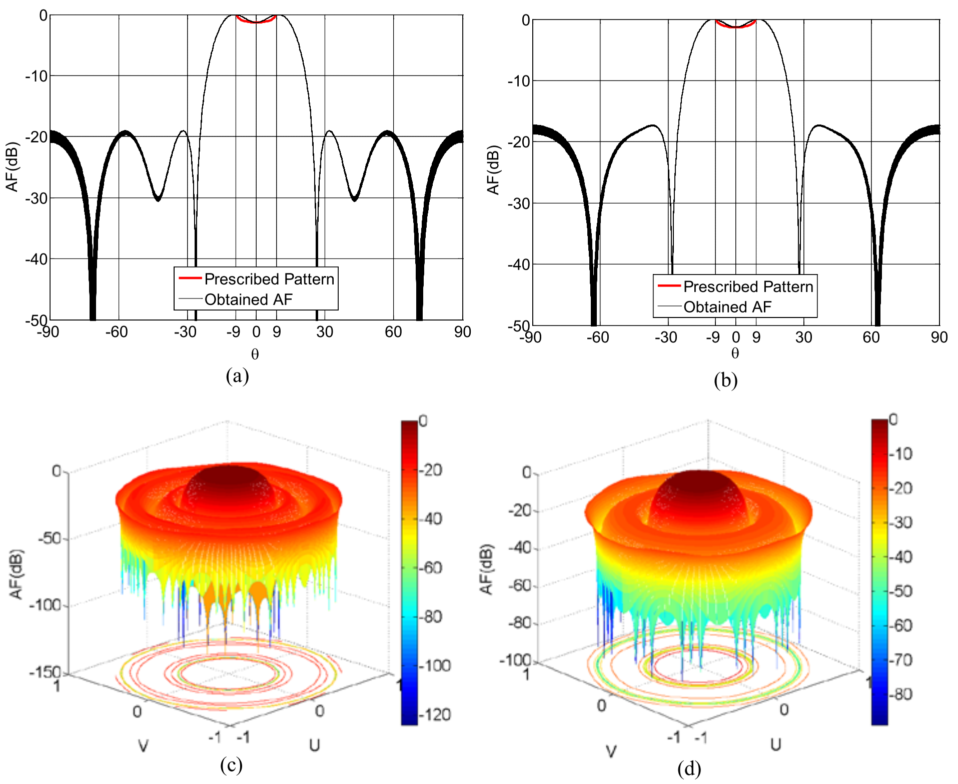


**Fig. 1.** Isoflux radiation in the elevation plane for the concentric ring array for: a) Case 1 and b) Case 2. Isoflux radiation considering both elevation plane and azimuth plane for: c) Case 1 and d) Case 2.


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011

Figure 1 shows the obtained isoflux radiation for both optimization cases in the elevation plane and in both elevation and azimuth planes. It could be appreciated that the PSO obtained an isoflux radiation with $SLL \leq -19$ dB for Case 1, and $SLL \leq -17$ dB for Case 2. If it is compared these results with respect to the designs presented in [5] and [6], it could be mentioned that the results presented in [6] require many excitation devices (amplitudes and phases) and a bigger aperture $A_{max} > 7\lambda$ in both axis, i.e., physical dimensions to achieve an isoflux radiation for the same application. Now, comparing the obtained results with the uniform planar array presented in [5], the array factor in Figure 1 for both optimization cases has less side lobe level using 3 (Case 1) and 2 levels (Case 2) of amplitudes and no-phase excitations with similar aperture $A_{max} < 5\lambda$ in both axis. From the point of view of needing to reduce the antenna hardware in the satellites, the obtained results for concentric ring arrays are suitable solutions for this particular application.

In Figure 2, it is presented the obtained distribution of the concentric ring array. Both optimization cases has similar aperture. For Case 1, the rings were distributed increasingly to the maximum obtained aperture. Moreover, note that for Case 2, the elements for the inner rings were kept in the center and the elements of the outer rings were distributed to the maximum

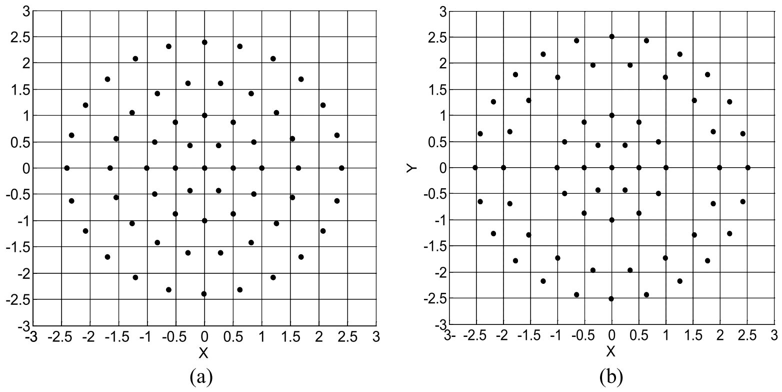


**Fig. 2.** Geometry of the obtained concentric ring arrays for: a) Case 1 and b) Case 2.

**Table I.** Numerical values of $SLL$ and excitations values for the optimization cases.

| Design | Case | $N_T$ | *SLL* (dB) | Levels of amplitudes (*L*) | Spacing rings (*S*) |
|---|---|---|---|---|---|
| Concentric ring | 1 | 61 | -19.04 | -3.6561 -0.2957 0.9586 | 0.5000 0.5000 0.6396 0.7592 |
| | 2 | 61 | -17.32 | -3.6692 0.4963 | 0.5000 0.5000 1.0000 0.5147 |
| Uniform | | | | Levels of amplitudes | Levels of phases |
| | Ref(5) | 61 | -15.000 | 2.0468 1.6225 0.8375 0.3256<br>0.0930 0.0155 1.2836 0.6694<br>0.2694 0.07810.3667 0.1573 | 1.6493 -1.5835 1.2944 -2.3064<br>0.4629 -2.8352 1.4724 -1.9987<br>0.6898 -2.8361 0.7542 -2.8430 |
| Sparse | Ref(6) | 100 | Not specified | Not specified | Not specified |


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011

obtained aperture. Furthermore, it can be mentioned that it is required a bigger amplitude excitation in the center of the array to achieve the desirable isoflux shaped pattern. The numerical values of side lobe level for the optimized array factors shown in Figures 1 are presented in Table 1. This Table shows the excitations required for the optimized designs depicted in Figure 2 for providing the isoflux radiation. Note that the optimizations provide a better $SLL$ reduction with less excitation devices with respect to the results presented previously in the literature, i.e., results shown in [5] and [6]. This could simplify considerably the feeding network for an isoflux radiation which it is desired for satellite applications.

## 4 Conclusions

This investigation reported a concentric ring array for GEO satellite applications with an isoflux radiation for a reduction of the side lobe level by using particle swarm optimization. The optimized designs perform a considerable reduction of side lobe level of $SLL \leq -17\,\mathrm{dB}$ and $SLL \leq -19\,\mathrm{dB}$. Under the assumption of the requirement of reducing the hardware of the antenna system and the isoflux radiation, the concentric ring array could provide an acceptable solution even more than the results presented previously in the literature. Future works could be focused on the applications of evolutionary algorithms for the simplifications of the feeding network.

## Acknowledgments

This work was supported by the Mexican National Science and Technology Council, CONACyT, under grant 127919 and the Science and Technology Council of Tamaulipas Mexico COTACyT under grant 2007-C13-73901 and 108166.


DOI: 10.1587/elex.8.484
Received March 01, 2011
Accepted March 16, 2011
Published April 10, 2011